ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 78 (2015) 1212 – 1217
Energy Procedia

6th International Building Physics Conference, IBPC 2015

IAQ Simulator tests: VOC emissions from hidden mould growth

Vuokko Lappalainen[a,b,*], Elina Sohlberg[b], Helena Järnström[c], Jarmo Laamanen[b], Hannu Viitanen[b], Pertti Pasanen[a]

[a]*University of Eastern Finland, Department of Environmental Science, P.O. Box 1627, FI-70211 Kuopio, Finland*
[b]*VTT Technical Research Centre of Finland, Tietotie 2, FI-02150 Espoo, Finland*
[c]*VTT Expert Services Ltd, Kemistintie 3, FI-02150 Espoo, Finland*

Abstract

Clean indoor air is a prerequisite for the welfare of the society. The Indoor Air Quality simulator (IAQ simulator) offers a research tool for building physic and building material research to evaluate the effect of the complicated causal connections of indoor air quality and multilayer building structures, materials and their unexpected exposure to moisture and microbial growth. In Microdiverbuild-project, the IAQ simulator was used to assess the drift of microbial metabolites (e.g. volatile metabolites of micro-organisms, MVOC) from a moisture damaged wall structure into indoor environment under various material moisture loads and pressure differences over the structure. Even low under-pressure has been found to cause infiltration of impurities in the indoor environment but unnecessary high under-pressure indoors increases further concentrations of impurities from the building structures. Also, infiltration of microbial gaseous contaminants from active mould growth inside the structure decreases indoor air quality.

The wood laths were covered by active mould growth, and represented a mould damaged wall structure (mould index 4-5). These laths were assembled inside the wall and simulated a hidden active mould growth having air leakage routes through the envelope. Two pressure difference levels simulated normal (low pressure difference) and unbalanced ventilation when pressure difference may increase as high as -20 Pa.The simulation test showed clearly MVOCs indicating hidden microbial growth. In our previous study, VOC profiles were developed based on building occupants complaints about poor IAQ, and found high ketone concentrations indicate mould problem which is equal with results of this study. However, it is known that MVOCs can be released from other sources in real buildings and the impact of relative humidity of the material is remarkable.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Indoor air quality, VOC, pressure difference, mould growth

* Corresponding author. Tel.: +358-40-724-8443.
E-mail address: vuokko.lappalainen@uef.fi

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.187

1. Introduction

Today people spend a substantial part of their time indoors and at the same time complaints of unacceptable indoor air quality (IAQ) are increasing. Poor indoor air quality in schools and offices has been shown to cause tiredness, unpleasant odour, discomfort, irritation, respiratory symptoms and other short- and long-term health problems [1][2][3]. Indoor air quality problems are usually complex and a sum of several factors or failures in the HVAC or building structures. The reparation of moisture, mould and decay damages fails often and there is a considerable need to further develop tools for monitoring and assessing the success of the renovation of a damaged building [4].

The function of building structures and ventilation has an important role on maintaining acceptable indoor air quality. In a case of mechanical exhaust ventilation type, controlled intake air inlets are needed. In reality, when a building is in under-pressure and there is a lack of controlled inlets, intake air flows through window frames and cracks in the structures as a leakage. Especially in cold climates, under-pressure can be very high during winter time when the temperature difference can be more than 40 °C between indoor and outdoor air.

In several studies, the possibility to evaluate microbial damage based on VOCs has been investigated. These compounds are volatile metabolites from micro-organisms (MVOC), and they are supposed to indicate the hidden mould growth in buildings. This assumption proved to be challenging because of low concentrations and variety between mould species, relative humidity and growth media [5][6], but also other sources of the same compound. Alcohols, ketones and terpenes found to indicate the mould growth on the building materials [7][8][9][10][11].

In the Microdiverbuild project, the aim is to develop a risk assessment model for indoor air failures. One part of the study was tests using Indoor Air Quality simulator. In these tests, the complex relationship between mould growth inside the structure and indoor air quality was simulated, and the source of a mould growth inside the wall structure was assessed. In this investigation, the impact of relative humidity changes of the material with and without mould growth on VOC emissions were evaluated under high and low pressure difference.

2. Materials and Methods

The IAQ simulator gives a new point of view for indoor air quality assessment. In the Microdiverbuild project, the simulator was used to assess the drift of impurities from the mould damaged wall under various material relative humidity conditions and pressure differences over the structure. The simulator was developed mainly at VTT [12][13], and it is based on the standard ISO 16000-9 [14]. The simulator consists of a supply air purification unit and a pressurisation unit and two test chambers (volume 0.5 m^3 per chamber). Between the chambers there was a frame where the tested structure was placed (see Fig. 1).

The case presented in this paper, consists of a wall structure of two gypsum boards, five upstanding pine sapwood laths, and mineral wool insulation. There were several 6 mm in diameter drilled holes as leakage routes on both of the gypsum boards. Other possible leakage routes from the borders of gypsum boards were sealed carefully with low-emitting aluminium tape. The computational leakage rate at 50 Pa pressure difference (n_{50}) of this wall structure in low and high pressure difference were 2.87 h^{-1} and 1.23 h^{-1}, respectively. The air change rate in the IAQ simulator was 1.0 1 h^{-1}, and incoming air flow was 8 l/min. The incoming air was purified from particles and VOCs (<20 µg/m^3), and humidified for clean and constant air quality. Also, all surfaces of the chamber and structures inside the simulator were cleaned with steam and 70 % ethanol dilution before and after every test runs. Chamber blanks were collected to assure sufficiently low background levels of VOCs.

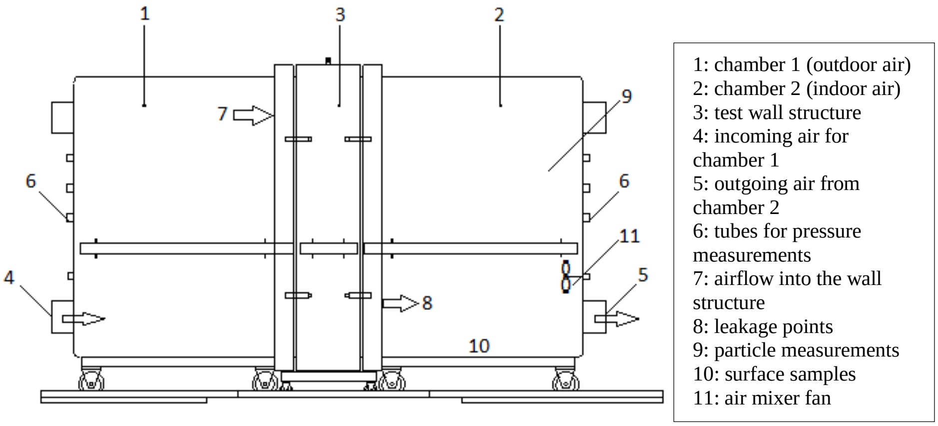

Fig. 1. The principle of the IAQ Simulator.

In these test runs, the pressure difference was at normal, low under pressure level (-2…-3 Pa) and for comparison high under pressure level (-18…-22 Pa) which is common in buildings with mechanical exhaust in cold climate. Even low under-pressure has been found to cause infiltration of impurities in the indoor environment. Infiltration of microbial and gaseous contaminants from mould growth inside the structure decreases indoor air quality. In this case, infiltration or air leakage refers to the uncontrolled air flow through the wall structure.

The effects of moisture stress in the bottom of the tested wall structure were tested both with a mould damaged and an undamaged (control) wall structure. In the moisture damaged wall, a mould suspension was inoculated on two sides of the wood laths and incubated for 4-6 weeks in high relative humidity. Inoculated species were *Aspergillus versicolor*, *Penicillium brevicompactum* (ATCC 58606), *Chaetomium globosum* (D-81079), *Cladosporium sphaerospermum*, *Paecilomyces variotii* (D-83214) and *Trichoderma viride.* An undamaged wall structure was used as a control case (no mould inoculated).

VOC samples were taken from indoor air chamber in Tenax TA adsorbent tubes according to the standard ISO 16000-6 [15]. The size of VOC samples varied between 2 and 6 litres. Tubes were analysed with ATD-GC/MSD (Agilent Technologies, Santa Clara, CA, US) SCAN technique, and calculated as toluene equivalents [15]. Compounds between hexane and hexadecane were analysed and total VOC (TVOC) concentrations were calculated from this area. The relative humidity of the material was measured with a surface sensor (Tinytag TV-4506, Gemini Data Loggers Ltd., Chichester, UK) format a height of 10 cm from the bottom of the wood lath. The pressure difference between indoor and outdoor chambers was measured continuously (SwemaFlow 300, SWA10, Swema AB, Farsta, Sweden).

3. Results

TVOC concentrations were clearly higher during the high moisture load period in first 6 days than during the dry period (days 10 and 13) in both control and damage cases (Fig. 2). In the control case, during the high pressure difference test wood material seemed to dry quicker compared to the damage case which may decreased the TVOC concentration in that case. In both high and low pressure difference, mould growth inside the wall structure increased the TVOC concentrations indoors clearly compared to the case without mould growth. Also, moist building material increased TVOC concentrations.

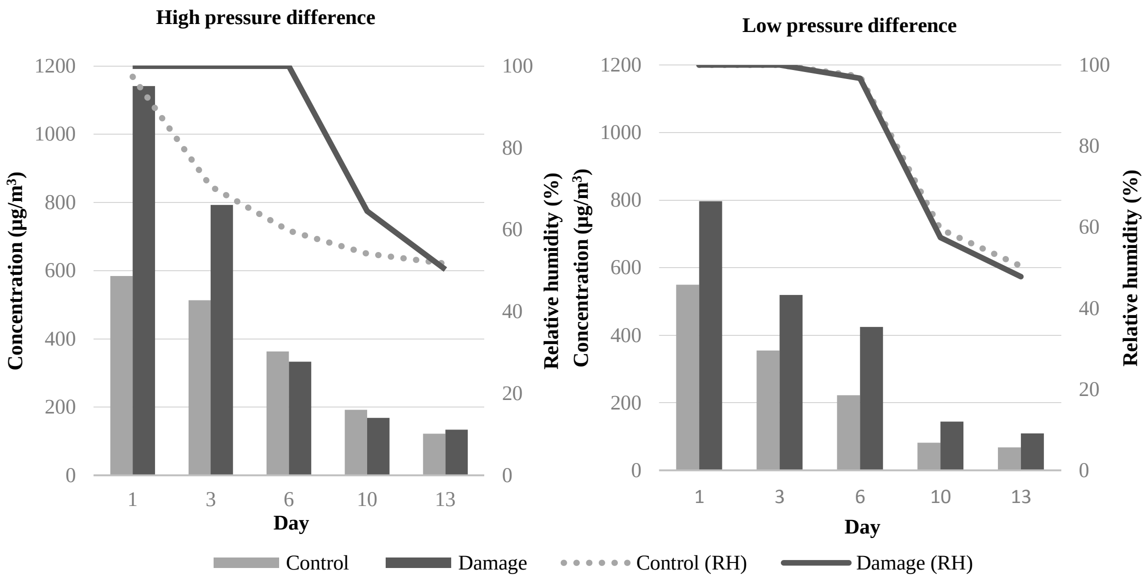

Fig. 2. TVOC concentrations and relative humidity of wood material.

The VOC compounds detected at highest levels in these simulations are presented in Tables 1 and 2. Clearly higher concentrations of ketones (2-pentanone, 2-hexanone, 2-heptanone, 2-octanone) were observed in the case of hidden mould growth (damage case) at both high and low pressure difference. However, aldehydes (hexanal) and one alcohol (1-pentanol) were found in higher concentrations in control cases with moist building materials. Terpene concentrations (α-pinene, 3-carene) were varying during test runs. Limonene, 1-butanol, and 2-ethyl-1-hexanol were in same order of magnitude in control and damage cases during the test runs.

Table 1. Single VOC compounds from test runs with high pressure difference.

	Day 1 (µg/m^3)		Day 3 (µg/m^3)		Day 6 (µg/m^3)		Day 10 (µg/m^3)		Day 13 (µg/m^3)	
Compound	Control	Damage	Control	Damage	Control	Damage	Control	Damage	Control	Damage
1-Butanol	18	19	6	7	< 2	< 2	< 2	< 2	< 2	-
2-Pentanone	-	228	-	146	3	38	< 2	14	< 2	10
1-Pentanol	13	3	13	3	8	< 2	3	< 2	2	< 2
2-Hexanone	-	55	-	33	< 2	9	-	3	-	2
Hexanal	17	5	11	5	6	< 2	2	< 2	2	< 2
2-Heptanone	2	90	< 2	72	< 2	23	< 2	7	< 2	4
α-Pinene	70	114	127	89	78	33	40	14	13	10
2-Octanone	-	48	-	46	-	23	-	9	-	6
3-Carene	-	116	54	76	72	27	-	12	10	8
2-Ethyl-1-Hexanol	22	20	11	17	8	11	5	9	5	8
Limonene	7	12	7	8	7	3	4	< 2	2	< 2

Table 2. Single VOC compounds from test runs with low pressure difference.

	Day 1 (μg/m^3)		Day 3 (μg/m^3)		Day 6 (μg/m^3)		Day 10 (μg/m^3)		Day 13 (μg/m^3)	
Compound	Control	Damage	Control	Damage	Control	Damage	Control	Damage	Control	Damage
1-Butanol	19	16	2	3	< 2	-	-	-	-	-
2-Pentanone	-	107	5	75	2	37	-	9	-	4
1-Pentanol	29	3	18	< 2	8	< 2	3	-	2	-
2-Hexanone	-	27	< 2	19	< 2	9	-	< 2	-	-
Hexanal	26	6	15	-	7	2	3	< 2	2	< 2
2-Heptanone	3	51	3	32	< 2	22	< 2	5	< 2	2
α-Pinene	36	53	53	42	50	84	6	11	4	8
2-Octanone	-	33	3	26	-	19	-	6	-	3
3-Carene	-	74	28	36	49	82	6	16	5	9
2-Ethyl-1-Hexanol	15	16	6	10	4	7	5	7	5	7
Limonene	4	10	4	6	6	6	< 2	< 2	< 2	< 2

4. Conclusions

The results presented in this paper are from the second stage of Microdiverbuild study. The results from the first stage of IAQ simulator tests have been presented in previous conference [16]. These results showed that the emission of microbial VOCs from a mould damaged wall structure can be simulated by using the IAQ simulator.

The wood laths were covered by active mould growth, and represented a mould damaged wall structure (mould index 4-5). These laths were assembled inside the wall and simulated a hidden active mould growth having air leakage routes through the envelope. Two pressure difference levels simulated normal (low pressure difference) and unbalanced ventilation when pressure difference may increase as high as -20 Pa.

The simulation test showed that there are microbial VOCs indicating hidden microbial growth. In the previous study where VOC profiles were developed based on building occupants complaints about poor IAQ, high ketone concentrations were found to indicate mould problem which is equal with results of this study. However, it is known that MVOCs can be released from other sources in real buildings and the impact of relative humidity of the material was found remarkable.

Acknowledgements

This study was funded by Academy of Finland (Microdiverbuild 253259), VTT Technical Research Center of Finland, Tekes (Bitefa project 40371/11) and University of Eastern Finland.

References

[1] Smedje G, Norback D, Edling C. Subjective indoor air quality in schools in relation to exposure. Indoor Air 1997; 7: 143-150.
[2] Apte MG, Fisk WJ, Daisey JM. Associations between indoor (CO2) concentrations and sick building syndrome symptoms in US Office Buildings: an analysis of the 1994-1996 BASE Study Data. Indoor Air 2000; 10: 246-257.
[3] Mendell MJ, Lei-Gomez Q, Mirer AG, Seppänen O, Brunner G. Risk factors in heating, ventilating, and air-conditioning systems for occupant symptoms in US office buildings: the US EPA BASE study. Indoor Air 2008; 18: 301-316.
[4] Haverinen-Shaughnessy U, Hyvärinen A, Putus T, Nevalainen A. Monitoring success of remediation: Seven case studies of moisture and mold damaged buildings. Science of the Total Environment 2008; 399: 19-27.
[5] Korpi A, Pasanen A-L, Pasanen P. Volatile Compounds Originating from Mixed Microbial Cultures on Building Materials under Various Humidity Conditions. Applied and Environmental Microbiology 1998; 64: 2914-2919.

[6] Sunesson A-L, Vaes W H J, Nilsson C-A. Identification of Volatile Metabolites from Five Fungal Species Cultivated on Two Media. Applied Environmental Microbiology 1995; 61: 2911-2918.
[7] Korpi A, Pasanen A-L, Pasanen P. Microbial Growth and Metabolism in House Dust. International Biodeterioration & Biodegradation 1997; 40: 19-27.
[8] Korpi A, Pasanen A-L, Viitanen H. Volatile metabolites of *Serpula lacrymans, Coniophora puteana*, *Poria placenta*, *Stachybotrys chartarum* and *Chaetomium globosum*. Building and Environment 1999; 34: 205-211.
[9] Wilkins K, Larsen K, Simkus M. Volatile metabolites from mold growth on building materials and synthetic media. Chemosphere 2000; 41: 437-446.
[10] Schleibinger H, Lauβmann D, Brattig C. Emission patterns and emission rates of MVOC and the possibility for predicting hidden mold damage? Indoor Air 2005; 15: 98-104.
[11] Lappalainen V, Järnström H, Pasanen P. VOC profiles indicating odour IAQ problems in dwellings. The 13th International Conference on Indoor Air Quality and Climate, Indoor Air 2014 July 7.-12. Hong Kong. USB flash drive.
[12] Paavilainen, J. Sisäilmasimulaattorin kehittäminen haihtuvien orgaanisten yhdisteiden emissioiden määritykseen (in Finnish). Master thesis 2005. Helsinki University of Technology, Department of Chemistry.
[13]Paavilainen, J; Järnström, H; Saarela, K; Sarlin, T; Viitanen, H; Airaksinen, M. 2007. Simulation of moisture and microbial problems in building. Proceedings. Clima 2007 - Well Being Indoors. Helsinki, Finland, 10 - 14 June. CD ROM, ss. Abstract book: 353. CD ROM: 1436 (8 p.)
[14] ISO 16000-9. Indoor air Part 9: Determination of the emission of volatile organic compounds from building products and furnishing. Emission test chamber method. 2006.
[15] ISO 16000-6. Indoor Air Part 6: Determination of volatile organic compounds in indoor and chamber air by active sampling on Tenax TA, thermal desorption and gas-chromatography MSD/FID. 2004.
[16] Lappalainen V, Sohlberg E, Järnström H, Laamanen J, Viitanen H, Pasanen P. IAQ simulator for evaluating the effects of moisture and microbial problems on indoor air quality. 10th Nordic Symposium on Building Physics, 15-19 June 2014 Lund, Sweden. Full Papers, s. 983-990. USB flash drive.